Journal of Forestry Research (2012) 23(4): 685–690
DOI 10.1007/s11676-012-0310-0

ORIGINAL PAPER

# A MCDM-based model for vendor selection: a case study in the particleboard industry

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Received: 2011-08-25; Accepted: 2012-01-31


**Abstract:** We investigated procurement of raw materials for particleboard to minimize costs and develop an efficient optimization model for product mix. In a multiple-vendor market, vendors must be evaluated based on specified criteria. Assuming sourcing from the highest-scoring vendors, annual purchase quantities are then planned. To meet procurement needs, we first propose a model to describe the problem. Then, an appropriate multi-criteria decision making (MCDM) technique is selected to solve it. We ran the model using commercial software such as LINGO® and then compared the model results to a real case involving one of the largest particleboard manufacturers in the region. The model run based real data yielded a procurement program that is more efficient and lower in cost than the program currently in use. Use of this procurement modelling approach would yield considerable financial returns.

**Keywords:** vendor selection; particleboard; multi-criteria decision making; forest; mathematical model

## Introduction

Since the late nineteenth century, most countries have used wood for making particleboard. In recent years, rates of forest destruction have been high due to rising demand for timber. Issues such as wildlife protection, government restrictions and environmental concerns imposed serious restrictions on forest utilization and caused wood prices to increase sharply (Cheng et al. 2004). It is necessary to discover alternatives to traditional uses of forest products, particularly those that are cost-effective.

Using wood waste and ligno-cellulose materials to produce particleboard has been a research focus for decades (Gürü et al. 2006). The economic advantage of low-cost wood, ligno-cellulose fibrous materials and relatively inexpensive adhesives such as UF resins, have led to successful development of particleboard production in the past decades (Ashori and Nourbakhsh 2010).

Global consumption of particleboard grew from 56.2 million $m^3$ in 1988 to approximately 104 million $m^3$ in 2006 (Zheng et al. 2006; FAO 2008). Published sources document a wide variety of studies searching for alternatives to wood as a raw material for particleboard (i.e. bagasse, wheat straw, rice stalk, sunflower stalk, tea leaves waste, etc.) (Nemli et al. 2009; Guntekin et al. 2008).

Table 1 summarizes recent studies of the feasibility and suitability of various raw materials in production of particleboard. The uses of fast growing trees such as eucalypt and poplar are well-known and proven by hundreds of studies and hence not referred to in Table 1.

Although many studies sought alternatives to wood from technical perspectives, the subject of production economics has rarely been considered. This research is an attempt to fill part of this gap. According to Wan Lung (2008), the models used in supplier selection are mainly based on data envelopment analysis (DEA), multi-objective optimization (MOP), simple multi-attribute rating technique (SMART) and analytic hierarchical process (AHP). To our knowledge, there is no research addressing the problem of vendor selection in the context of particleboard production using different wood and non-wood materials.

In this research, a well known company called Sanate Choube Shomal is selected as one of the three top companies both in terms of quantity and quality. The company has over thirty years of experience, with an installed production capacity of 80,000 cubic meters per year. The company has a market share of 12% of the Iranian particleboard market. Its machinery and equipment were originally designed so that wood, plantation wood and ligno-cellulose materials can be used. Their facilities are well

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suited to the use of alternative fiber sources.

Raw materials such as wood, ligno-cellulose, bagasse, wheat and rice stalk, date palm residues and eucalypt are available domestically in limited quantities. In terms of transport distance, use of varying mixtures of these materials can affect the cost and quality of finished particleboard. Costs for raw materials and transport depend on the type of raw material and the location of the supplier. Because of limitations on the supply capacity for raw materials, no single material or supplier can satisfy the long-term demand at Sanate Choube Shomal. Manufacturers must be sensitive to the impact of their raw material mix on the quality of finished board because there are industry standards for manufactured particleboard.

Among the challenges facing Iran's particleboard industry, the shortage of wood resources is most important (Fadaei 2011). During the last five years, many attempts were made at Sanate Choube Shomal to use ligno-cellulose materials (such as wheat straw, rice stalk and bagasse), eucalypt, and wood from plantations along with wood from natural forest. Currently used industrial accounting procedures cannot accurately calculate the impacts of raw material costs on the total cost of finished particleboard, thus cannot provide information needed by senior managers. Company records show that despite the negative consequences caused by bad performance of some vendors, no systematic procedure was used to evaluate them.

In this research, we used a mathematical model to determine the optimum production mix from an economic viewpoint and to quantify procurement of raw materials from vendors receiving the highest scores for efficiency in material supply.

**Table 1. A summary of recent studies on possible and suitable raw materials for production of particleboard**

| Raw material | Reference | Research findings |
|---|---|---|
| maize stalk residue | Ajaye 2011 | • It is proved that maize stalk residues are suitable to produce cement-bonded particleboard. |
| sunflower stalk, corn stalk, bagasse fibres | Ashori et al. 2010 | • In all cases, the agricultural residuals investigated, are suitable as an alternative to wood.<br>• Bagasse fibres show the best mechanical properties among the others. |
| bagasse | Xu et al. 2009 | • The modulus of rupture (MOR), modulus of elasticity (MOE) and internal bond (IB) values all met the minimum requirements of M3 grade in the ANSI standard. |
| kenaf | Kalaycıoglu et al. 2006 | • Both physical and mechanical properties of the panels are comparable to boards made from other agricultural residues.<br>• Kenaf has potential as a raw material for particleboard manufacturing. |
| kiwi pruning | Nemli et al. 2003 | • Containing up to 50% kiwi pruning particles in the core layer, the MOR exceed the minimum specifications of the European standards.<br>• All of the boards produced from kiwi pruning had IB higher than the requirement. However, the water absorption (WA) and thickness swelling (TS) values were very high. |

## Method

Problem definition

The objective of this study was to determine the optimum mix of raw materials to meet industry specifications while minimizing production costs. We investigated the limitations of suppliers in light of industry specifications. To evaluate suppliers, we considered several factors, including raw material price, supply capacity and reputation.

Problem formulation

Using a mathematical framework, the model is described in detail in the following sections.

*Model assumption*

**Wood raw materials:** The required raw materials can be provided from various domestic sources (mainly in the form of wood from forests, plantation wood, slabs from sawmills.) as well as overseas sources (mainly in the form of wood chips).

**Non-wood raw materials:** Non-wood raw materials such as wheat straw, rice stalks, and bagasse are supplied in bulk and in bales. Because the bulk density of such materials is low, purchase of bales is less costly. Therefore the model assumes these materials to be in the form of bales.

**Total logistic costs and purchase costs:** The total logistics costs are composed of six major components: cost of purchase, cost of transport, cost of discharge, cost of mechanical transformation, and finally cost of energy. Because the cost of storage is constant for all raw materials, it does not affect the objective function and we did not include it in the model.

**UF Resin:** Both liquid and powder UF resins are appropriate for use in the process. The liquid form is the most cost effective and commonly used resin. Therefore, the model selects liquid resin.

**Production**: Wages and overhead costs are constant regardless of raw material input so we ignored these in the model.

**Technology:** Hardware aspects of technology (e.g. machinery, equipment, tools, etc.) used in production will be unchanged and the model does not force any investment in machinery and equipments.

*Model outputs*

**Type and amount of raw materials:** Type and amount of raw materials required for one unit of finished product (i.e. one cubic meter particleboard).

**Type of vendor:** Type of vendors and the volume of related raw materials are required for production of one unit of finished

product.

*Model objectives*

• Price of raw materials should be minimized.

• The weighted scores related to selected vendors should be maximized.

*Model constraints*

**Consumption coefficient:** The required amount of each raw material per unit of finished product should be less than or equal to consumption coefficient (i.e. the amount consumed per one unit of finished product in the event only one type of raw material is used in production).

**The percentage of raw material:** The percentage of raw material consumed per one unit of finished product should be less than or equal to maximum allowable percentage of its usage

**The score of each vendor:** The score for each vendor is equal to the sum of weighted scores for that vendor under different criteria. The weighted score for each vendor is obtained by multiplying the weight of each criterion by the score of each vendor under that criterion.

**Total amount of raw materials:** Total amount of raw materials purchased from each vendor should be less than or equal to maximum delivery capacity of that material for that vendor.

*Model inputs*

The inputs of the model include type and number of raw material vendors, evaluation criteria and their weights, cost of procurement, consumption coefficient of raw materials, the maximum allowable amount of raw materials to use, type and amount of raw materials supplied by each vendor, quality of raw materials supplied by each vendor, vendor delivery schedules, price of raw materials supplied by each vendor, reputation and position of each vendor in the market, and facilities and capacity of each vendor.

The total cost of raw materials includes various component costs. Therefore it is necessary to identify all cost components for each raw material to calculate total cost. These costs include purchase cost, transport cost, discharge cost, wood-infeeding cost mechanical transfer cost, and consumed energy cost.

*Model mathematical framework*

In the mathematical framework, the model elements, including indices, variables, parameters, and symbols, are described as follows:

**Indices:**

$i$: index for the evaluation criteria, e.g. price, reputation, quality, capacity, for all $i$= 1, 2, …, $l$

$j$: index for vendors of raw materials, for all $j$= 1, 2, …, $m$

$k$: index for type of raw material, e.g. forest wood, plantation wood, shaving, flake or bagasse, for all $k$= 1, 2, …, $n$

**Variables:**

$X_{jk}$: the amount of raw material bought from supplier $j$ (kg)

$Z_1$: the first objective function (to minimize cost of procurement of raw materials)

$Z_2$: the second objective function (to maximize scores for suppliers)

**Parameters:**

$a_k$: the maximum quantity allowable consumption of raw material $k$ per each unit of finished product (kg·m$^{-3}$)

$b_k$: the maximum allowable ratio of consumption of raw material $k$ per each unit of finished product (%)

$S_{ij}$: the score of supplier $j$ under criterion $i$

$V_{ij}$: the weighted score of supplier $j$ under criterion $i$

$V_j$: the weighted score of supplier $j$ under all criteria

$W_i$: the weight of criterion $i$

$c_{jk}$: procurement price of raw material $k$ from vendor $j$ (US $)

$d_{jk}$: capacity of vendor $j$ for raw material $k$

$l$: the total number of criteria

$m$: the total number of suppliers

$n$: the total number of raw materials

*Vendor evaluation and selection*

This subsection provides systematic approaches to evaluate and score potential suppliers based on multiple criteria. The evaluation process involves two stages. In the first stage, we conducted a four-round Delphi study to survey major criteria during the period February-April 2010 (Arian 2008). Each round took two to three weeks for completion. The purpose of the first round was to elicit opinions from a group of experts, the second round was to validate the findings of the previous round, the third round was to reduce the list of opinions to a manageable size, and the final round was to rank the reduced list to reach a close consensus.

In the literature on supplier selection, Dickson's vendor selection criteria (Dickson 1966) are dominant and are likely to continue to dominate. Among Dickson's 23 criteria, price, reputation and position in market, quality, facilities and capacity, and delivery were selected as the most important criteria in the final round of the Delphi process. The five selected criteria are briefly described below:

**Quality:** the ability to meet quality specifications consistently. For new vendors the quality should be determined by sampling and tests. For existing vendors the quality should be determined by purchasing records and quality control department archives.

**Delivery:** the ability to meet specified delivery schedules

**Price:** the average annual sale price, including transport costs

**Reputation and position in market:** the position in marketplace including a good reputation

**Capacity:** the annual quantity of raw material available for purchase from a vendor.

In the second stage, the collected data were used to calculate the total weighted score. Each criterion $i$ was assigned a weight ($w_i$) that reflects its importance (Table 2). The performance of supplier $i$ under criteria $j$ was denoted as $S_{ij}$ and then the weighted scores for each vendor $j$ under criterion $i$ were obtained by multiplying the weight by the score. The total weighted score for each vendor was obtained by summing the weighted scores. The equations were:

$$V_j = \sum_{i=1}^{l} v_{ij} = \sum_{i=1}^{l} S_{ij}.w_i \qquad j = 1,2,...,m \tag{1}$$

Where,

$$\sum_{i=1}^{l} w_i = 1 \tag{2}$$

• ***Price:*** measured on a five-point Likert (Likert 1932) scale, ranging from 1 (highest) to 5 (lowest).

• ***Reputation:*** measured on a five-point Likert scale, ranging from 1 (worst) to 5 (best).

• ***Quality:*** measured on a five-point Likert scale, ranging from 1 (poorest) to 5 (best).

• ***Capacity:*** measured on a five-point Likert scale, ranging from 1 (least) to 5 (most).

*Model*

The decision variables and input parameters defined in previous subsections were used to develop the two linear functions for cost and scores subject to appropriate constraints. The models were:

$$Min.Z_1 = \sum_{j=1}^{m}\sum_{k=1}^{n} C_{jk}.X_{jk} \tag{3}$$

$$Max.Z_2 = \sum_{j=1}^{m}\sum_{k=1}^{n} V_j.X_{jk} \tag{4}$$

$$\sum_{j=1}^{m} X_{jk} - a_k \le 0 \qquad \forall k = 1,2,...n \tag{5}$$

$$\sum_{j=1}^{m} X_{jk} - b_k \sum_{j=1}^{m}\sum_{k=1}^{n} X_{jk} \le 0 \qquad \forall k = 1,2,...n \tag{6}$$

$$\sum_{k=1}^{n} \left(\frac{\sum_{j=1}^{m} X_{jk}}{a_K}\right) - 1 = 0 \tag{7}$$

$$X_{jk} - d_{jk} \le 0 \quad \forall j = 1,2,...m \quad \forall k = 1,2,...n \tag{8}$$

$$\begin{gathered} a_k, b_k, C_{jk}, d_{jk}, V_j, X_{jk} \ge 0 \\ \forall i = 1,2,..l \;\; \forall k = 1,2,...n \;\; \forall j = 1,2,...m \end{gathered} \tag{9}$$

Equation 3 is the first objective function that gives the total cost of raw materials. Equation 4 is the second objective function that gives the total weighted scores of vendors. Constraint Equation 5 expresses the fact that the required amount of raw material $k$ per each unit of final product is less than or equal to the maximum allowable amount ($n$ constraints). Constraint Equation 6 indicates that the percentage of raw material $k$ used per unit of final product is less than or equal to the maximum allowable amount (n constraints). Constraint Equation 7 ensures that the sum of all percentages equals 100%. (one constraint). Constraint Equation 8 indicates that all parameters and decision variables are nonnegative ($m$+2$mn$+2$n$ constraint).

This model has two objective functions, $mn$ positive decision variables, and 4$n$+3$mn$+$m$+1 constraints.

## Results

Problem solving

Considering the linear nature of the proposed model, a category of Multi Objective Decision Making (MODM) problems, we used the multi-objectives techniques to solve it. We used Lingo® 8.00 software to solve the numerical problem based on a real data set. The model yields two objective functions, one in the form of score function maximization, and the other in the form of cost function minimization, subject to the same set of linear constraints. The combined objective function (to be minimized) is formulated as:

$$Min \quad U_p = \left(\left(Z_1 - Z_1^*\right)/ Z_1^*\right)^p + \left(\left(Z_2^* - Z_2\right)/ Z_2^*\right)^p \tag{10}$$

Validity and sensitivity analysis

The real procurement situation of the company can be investigated from two aspects.

• **Purchasing raw materials:** Procurement methods are not specified but are based on trial and error. As a result, the company has encountered many difficulties in procurement.

• **How to use raw materials in production mix:** Recent use of raw materials in the production mix is shown in Table 2, involves use of seven types of raw material.

**Table 2. Current production mix**

| Type of raw material | Consumption per year (kg) | Consumption per unit of product (kg) | Share of each raw material in mix (%) |
|---|---|---|---|
| Forest wood, subcontracted | 12,534,040 | 159.05 | 10.35 |
| Forest wood | 24,448,814 | 310.24 | 20.18 |
| Plantation wood | 76,414, 719 | 969.65 | 63.1 |
| Shavings | 7,371,595 | 93.54 | 6.08 |
| Bagasse | 22,215 | 0.28 | 0.018 |
| Wheat straw | 305,860 | 3.88 | 0.25 |
| Rice stalk | 26,735 | 0.34 | 0.02 |

Comparison of model results vs. real situation

Model results can be assessed from two aspects: the first is the weighted scores of raw materials supplied by each vendor, and the second is the cost of raw materials supplied by each vendor.

Comparison of the weighted scores of raw materials purchased

The output of this model ranks vendors that supply raw materials. Because the company uses no systematic procedure for evaluating and selecting vendors, this model output has the following three advantages: (1) Procurement based upon this output would have the least bad consequences; (2) Long-term, continuous use of this model could lead to improve purchasing policies (e.g. decrease in purchase order quantity from vendors having less scores); and (3) The obtained results can be used as inputs for model runs in future to adapt procurement to performance histories.

Comparison between raw material mix vs. procurement costs

The cost savings of USD 58.10 per cubic meter of finished product were projected by the model (Table 3). $X_1$, $X_2$, $X_3$, $X_4$, $X_5$, $X_6$ and $X_7$ represent plantation wood, forest wood, forest wood (subcontracted), shavings, wheat straw, rice stalk and bagasse, respectively. Production of over 80,000 cubic meters of finished product annually would yield total savings in excess of USD 500,000 US dollars, or approximately 10 percent of the total finished product cost.

**Table 3. Comparison of the model to current situation, and obtained savings**

| | $Z_1$ | $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_6$ | $X_7$ |
|---|---|---|---|---|---|---|---|---|
| Current cost | 439.70 | 159.05 | 310.24 | 969.65 | 93.54 | 0.28 | 3.88 | 0.34 |
| Model-projected cost | 381.60 | 61.06 | 80 | 1000 | 150 | 0 | 100 | 154.56 |

Saving = 439.70 – 381.60 = USD 58.10 per cubic meter of finished product

Sensitivity analysis

Sensitivity analysis assesses impacts to model outputs caused by fluctuations in parameters and factors (like right-hand sides of the constraints, objective function coefficients, and adding a new constraints). In this model, the right-hand sides of constraints did not represent rare resources but rather indicated the affects of technical, technological, and quality restrictions or specifications. Therefore investigating these would have no significant impacts on model outputs. Since all technical, technological, and quality constraints were considered in model-building, we have no new constraints to add to the model for sensitivity analyses.

Objective function coefficients indicate costs of raw materials which is the most important factor affecting the results of the model. The effect of changes to these coefficients is shown in LINGO® software output in the *Reduced Costs* column.

The Reduced Costs column in LINGO® software output lists information relating to non-basic variables. For each non-basic variable the reduced cost is the amount by which the coefficient must be improved for this variable to become a basic variable.

Reduced costs of non-basic variables $X_{11}$, $X_{31}$, $X_{61}$, $X_{81}$, and $X_{91}$, are 3.4, 1.7, 1.7, 3.4, and 4.25, respectively. This means that if we increase the coefficients of these variables by amounts greater than the projected reduction in cost, the basis would be changed. Thus it is necessary to investigate these figures (e.g. procurement cost of forest wood) accurately because small changes to them can change the basis. Therefore, approach to improving the current procurement procedure is to decrease procurement cost of forest wood and/or to decrease the proportion of this material in the raw material mix.

Reduced costs of non-basic variables $X_{15}$, $X_{25}$, $X_{35}$, $X_{45}$, $X_{55}$, $X_{65}$, $X_{85}$, $X_{95}$, are 6.8, 3.4, 5.1, 1.7, 0.85, 5.1, 6.8, and 7.6, respectively. This implies, for example, that even if the procurement cost of bagasse declines to the specified amounts, the basis would not change. The basis would change only when procurement cost of bagasse declines more than these amounts. Two approaches to reducing the cost of including bagasse in the raw material mix, therefore, would be to increase the consolidation coefficient of bagasse bales and install and commission a bale breaker machine.

The Dual Prices column lists shadow (or dual) prices. Dual prices of zero indicate that an increase of one unit of relative variable would not change the total cost of procurement.

## Discussion

Since the late nineteenth century most countries (including Iran) have used forest wood to produce particleboard because of its low price and ready availability. Although many efforts and studies have aimed to investigate the feasibility of using alternatives such as ligno-cellulose (e.g. wheat stalk, rice stalk, bagasse, kenaf, corn stalk, tea leave wastes, sunflower stalk) and non-forest wood (e.g. eucalypt, spruce), forest wood has typically been available at lower prices, so successful research findings have not received the attention of manufacturers. Recently, due to increasing forest degradation, increases in raw material prices, and stricter environmental regulations, producers are seeking alternative raw materials to reduce their vulnerability to higher production costs.

In this paper, we present an efficient model to prescribe the best mix of raw materials to minimize procurement costs while meeting industry requirements for finished product quality. Because particleboard producers use multiple vendors, we considered the maximizing of the weighted scores of vendors as a secondary objective. We compared our model outputs with a real situation at an established company. This indicated potential savings of USD 500,000 per year. Our research also yielded a systematic approach for evaluation and selection of vendors. Suggestions for future researches are as follows:

The output of the model describes the optimum amount of each raw material needed to produce one unit of final product, and identifies preferred vendors. Each vendor has its own resources that determine its capacity to deliver raw materials. On the other hand particleboard producers have procurement policies that aim to prevent inventory variations (e.g. purchasing

materials in large lots). Because raw material prices can determine market prices for finished product, a suggestion for future researches is to design efficient inventory models to determine order quantities of raw materials with respect to the supply capacities of vendors.

Since a company involved in vendor selection faces many risks, another suggestion for future research is analysis of risk and the role of risk in the process of vendor evaluation and selection.

One of the most important company activities is procurement of wood raw material, particularly eucalypt. Because wheat and rice stalk is abundant in nearby areas, companies should study the feasibility of making particleboard using a mixture of eucalypt, wheat stalk and rice stalk.

One model assumptions is that the same machinery can be used for particleboard production when using non-wood raw materials such as wheat stalk, rice stalk and bagasse. This can limit the use of these raw materials in the production mix. An effective research project would, therefore, be the design an efficient model to optimize raw material mix for making particleboard. Use of different types of equipment (such as bale press, bale breaker machine, depither machine) along with small modification in process, would enable increases in the allowable proportions of lignocellulose materials in the mix.

Because each type of raw material requires its own storage method, future research in modeling should use simulation techniques to focus on storage of raw materials with respect to factors such as ease of use, cost price, and safety.

Raw material prices are increasing at a faster rate that is sale price of finished particleboard. This raises issues such as import of wood, and acceleration of Iran's inflation rate. These factors encourage researchers to design a model to predict particleboard cost prices in relation to predicted trends in raw materials prices, particleboard selling prices, and elasticity of demand.

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